

# **Lessons Learned from AIRS: Improved Determination of Surface and Atmospheric Temperatures Using Only Shortwave AIRS Channels**

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# AIRS

AIRS is a grating detector array spectrometer launched on Eos Aqua in May 2002

Provides information about surface and atmospheric temperature, water vapor and constituent profiles, and clouds

Measures upwelling radiance  $\hat{R}_i$  in 2360 spectral channels  $i$  between  $650 \text{ cm}^{-1}$  and  $2665 \text{ cm}^{-1}$

$\nu_i / \Delta \nu_i \approx 1200$       $\Delta \nu_i$  goes from  $0.5 \text{ cm}^{-1}$  -  $2.2 \text{ cm}^{-1}$

Spatial resolution  $\approx 13 \text{ km}$  at nadir from  $705 \text{ km}$  orbit

Referred to as AIRS Field of View (FOV)

AIRS was accompanied by AMSU-A

Microwave temperature profile sounder

Spatial resolution  $\approx 45 \text{ km}$  at nadir

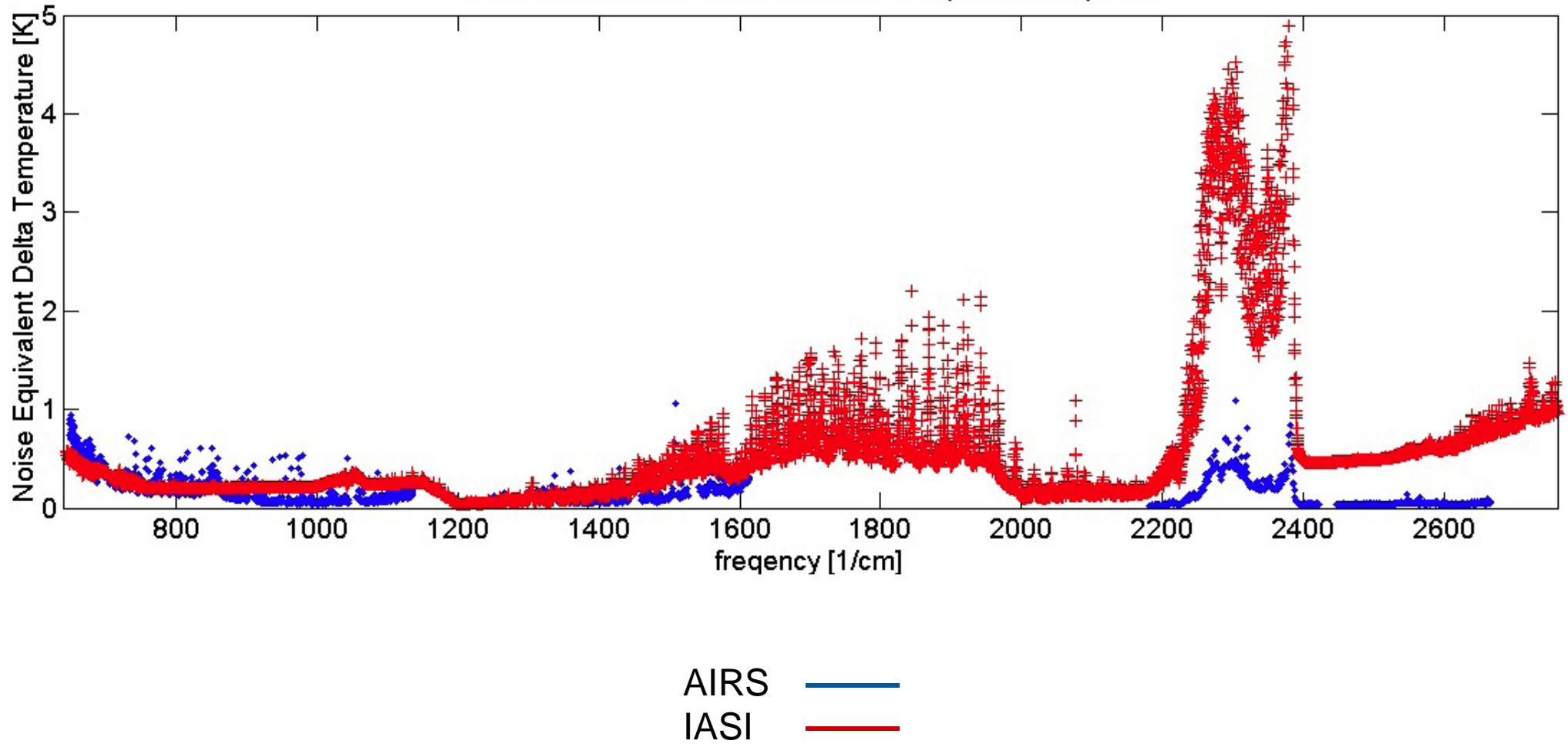
Referred to as AIRS Field of Regard (FOR)

9 AIRS FOV's fall within one FOR

AIRS was designed specifically to have very low noise at short wavelengths

IASI, a high spectral resolution IR interferometer on METOP-A, has much higher noise at short wavelengths

AIRS and IASI NEDT evaluated for a tropical atmosphere



# Overview of AIRS Science Team Retrieval Methodology

Physically based retrieval system

Independent of GCM except for surface pressure - used to compute expected radiances

Uses cloud cleared radiances  $\hat{R}_i$  valid for AIR FOR to determine the solution

$\hat{R}_i$  represents what AIRS would have seen in the absence of clouds

Derivation of  $\hat{R}_i$  is updated in different steps of the retrieval process

## Basic steps

Initial cloud clearing produces  $\hat{R}_i^0$  - based on statistical initial guess using observed radiances  $R_i$

Sequentially determine surface parameters,  $T(p)$ ,  $q(p)$ ,  $O_3(p)$ ,  $CO(p)$ ,  $CH_4(p)$ , using  $\hat{R}_i^0$

Each step uses its own set of channels

Generate error estimates  $\delta T(p)$ ,  $\delta q(p)$  and use for Quality Control (QC)

Retrieval system can be used with AIRS/AMSU radiances or in “AIRS Only” mode without AMSU radiances

Goddard DISC had been analyzing AIRS/AMSU data using AIRS Version-5 algorithm

Retrievals are near real time

Analyzed data from September 2002 through the present

AIRS Science Team Version-6 algorithm will become operational in late 2011

# Objectives of AIRS/AMSU

## **Provide real time observations to improve numerical weather prediction via data assimilation**

Could be  $R_i$  (used by NCEP, ECMWF) or  $T(p)$ ,  $q(p)$

Accuracy of  $\hat{R}_i$ ,  $T(p)$ ,  $q(p)$  degrades slowly with increasing cloud fraction

There is a trade-off between accuracy and spatial coverage

Assimilation of soundings or radiances only in clear cases limits utility of the data

Assimilation of poorer quality retrievals can degrade forecast skill

## **Provide observations to measure and explain interannual variability and trends**

Must provide good spatial coverage but also be unbiased

Can be less accurate than needed for data assimilation

## **Use of AIRS product error estimates allows for QC optimized for each application**

Tighter QC is better for data assimilation

Looser QC is better for climate applications

# Significant Improvements in AIRS Retrieval Methodology

## Improvements in AIRS Version-5

Improved radiative transfer parameterization accounts for effects of Non-Local Thermodynamic Equilibrium (non-LTE)

Allows for complete use of  $4.3\ \mu\text{m}$   $\text{CO}_2$  sounding channels to determine  $T(p)$

Following theoretical considerations:

$R_i$  for  $15\ \mu\text{m}$   $\text{CO}_2$  channels are used only for cloud clearing coefficients

Gives clear column radiances  $\hat{R}_i$  for all channels

$\hat{R}_i$  for  $4.3\ \mu\text{m}$   $\text{CO}_2$  channels are used to determine temperature profile  $T(p)$

This allows for accurate  $T(p)$  soundings under more difficult cloud conditions

## Further improvements in Version-6

Only shortwave window channels are now used to determine  $T_{\text{skin}}$ , shortwave surface spectral emissivity  $\epsilon_{\text{SW}}^{(v)}$ , and bi-directional reflectance  $\rho_{\text{SW}}^{(v)}$

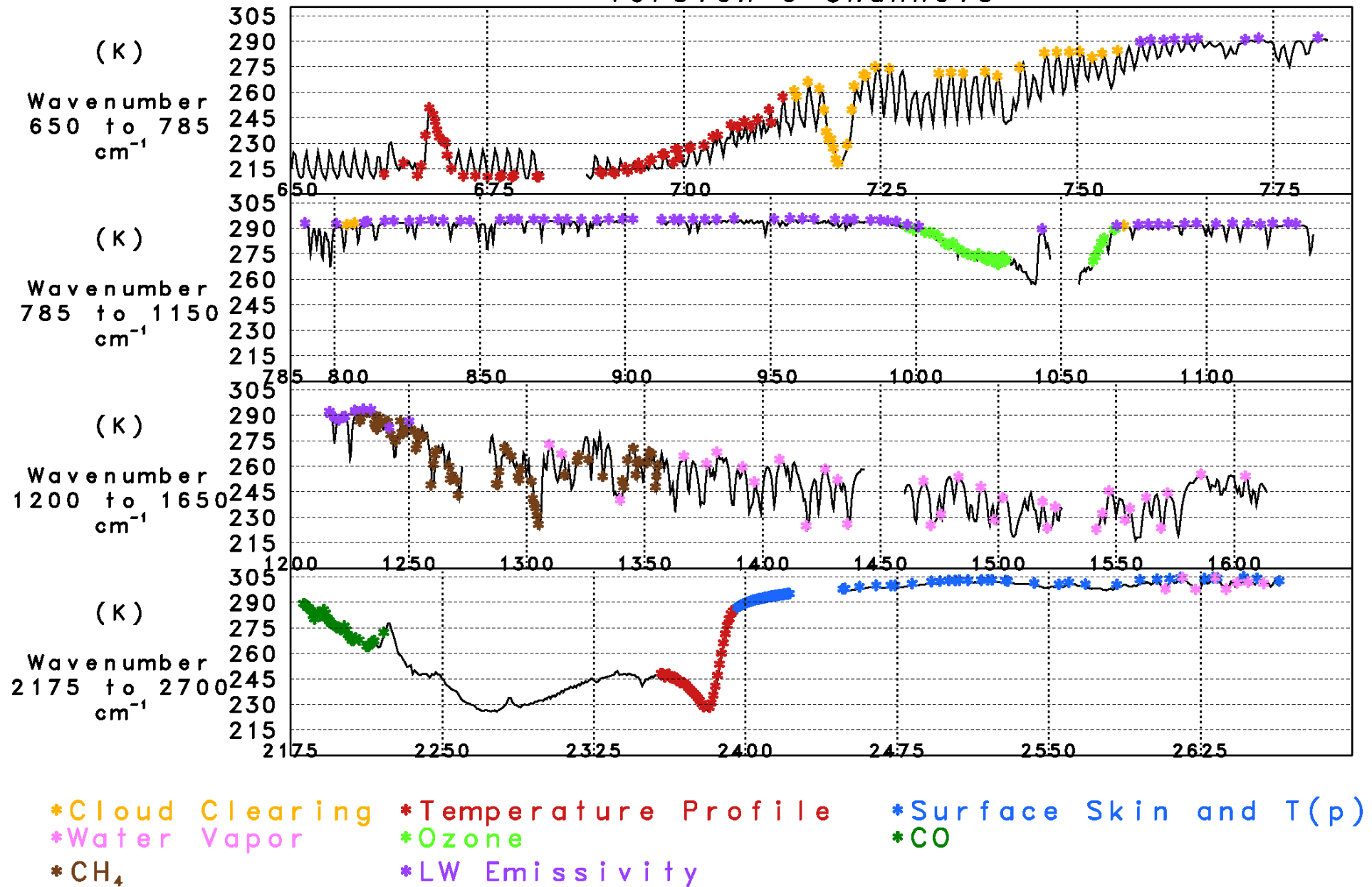
$\hat{R}_i$  in longwave window channels are used in a subsequent retrieval step to

determine  $\epsilon_{\text{LW}}^{(v)}$  given  $T_{\text{skin}}$

This provides accurate surface soundings under more difficult cloud conditions

Version-6 also has other improvements compared to Version-5

# Sample AIRS Cloud Free Brightness Temperature Version 6 Channels



# Methodology Used for T(p) Quality Control

## Version-5

Define a profile dependent pressure,  $p_{\text{best}}$ , above which the temperature profile is flagged as good - otherwise flagged as bad

Use error estimate  $\delta T(p)$  to determine  $p_{\text{best}}$

Start from 70 mb and set  $p_{\text{best}}$  to be the pressure at the first level below which  $\delta T(p) > \text{threshold } \Delta T(p)$  for 3 consecutive layers

Temperature profile statistics include errors of  $T(p)$  down to  $p = p_{\text{best}}$

Version-5 used  $\Delta T(p)$  thresholds optimized simultaneously for weather and climate :  $\Delta T^{\text{standard}}(p)$

Subsequent experience showed  $\Delta T^{\text{standard}}(p)$  was not optimal for data assimilation (too loose) or for climate (too tight)

Use of new tighter thresholds  $\Delta T^{\text{tight}}(p)$  resulted in retrievals with lower yield but with RMS errors  $\approx 1\text{K}$

Performed much better when used in data assimilation experiments

## Version-6

QC is analogous to Version-5 but has tight thresholds  $\Delta T_A(p)$  for data assimilation and loose thresholds  $\Delta T_C(p)$  for climate applications

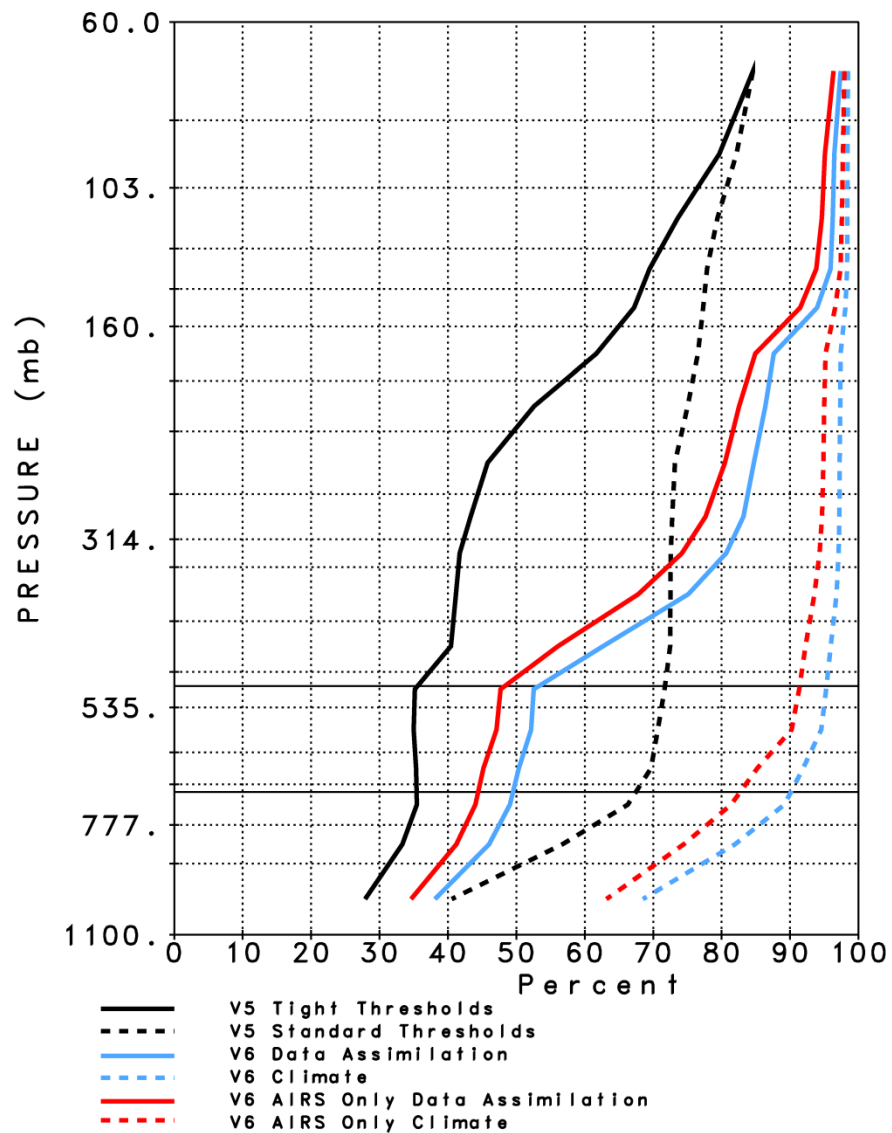
$\Delta T_A$  thresholds define  $p_{\text{best}}$  and  $\Delta T_C$  thresholds define  $p_{\text{good}}$

$\Delta T_A$  thresholds designed to give RMS errors  $\approx 1\text{K}$

$\Delta T_C$  thresholds are used to generate level-3 gridded products

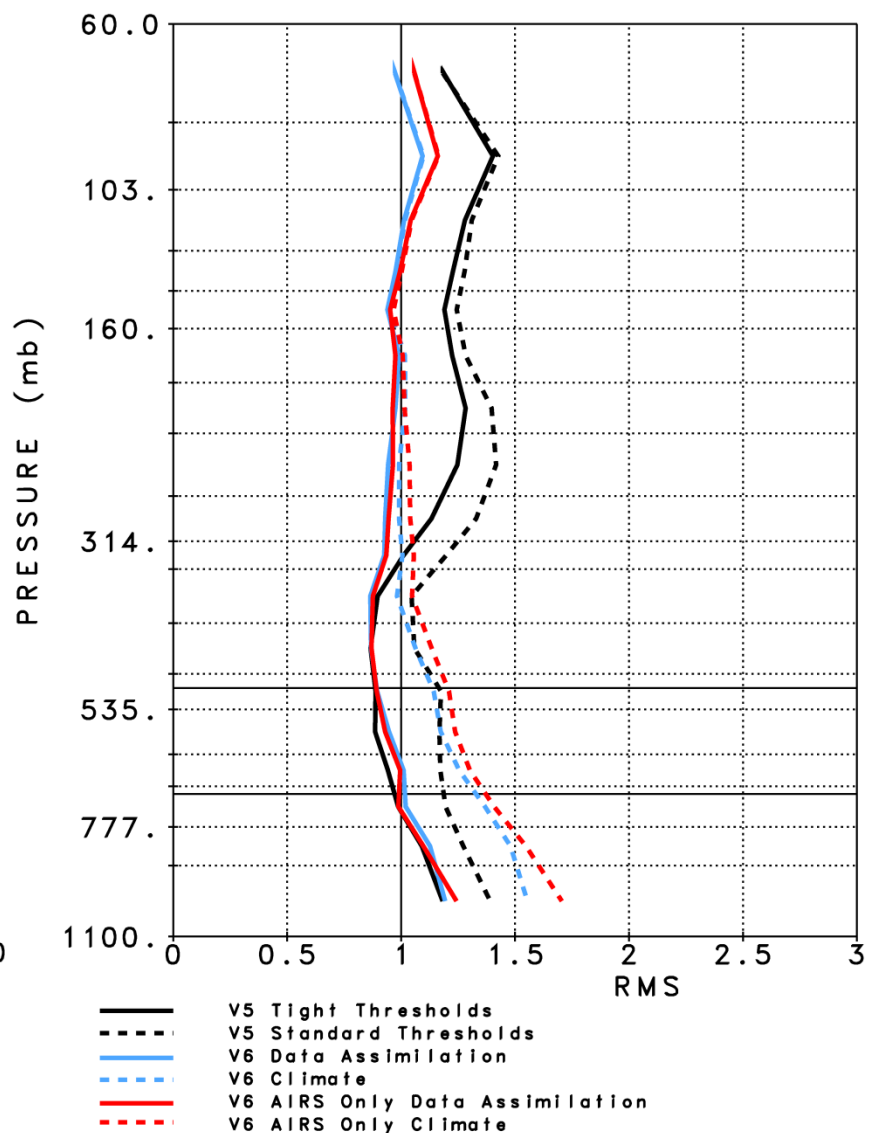
# Percent of All Cases Accepted

6-Day Average  
Global



# LAYER MEAN RMS TEMPERATURE ( $^{\circ}$ K)

Differences from ECMWF  
6-Day Average  
Global

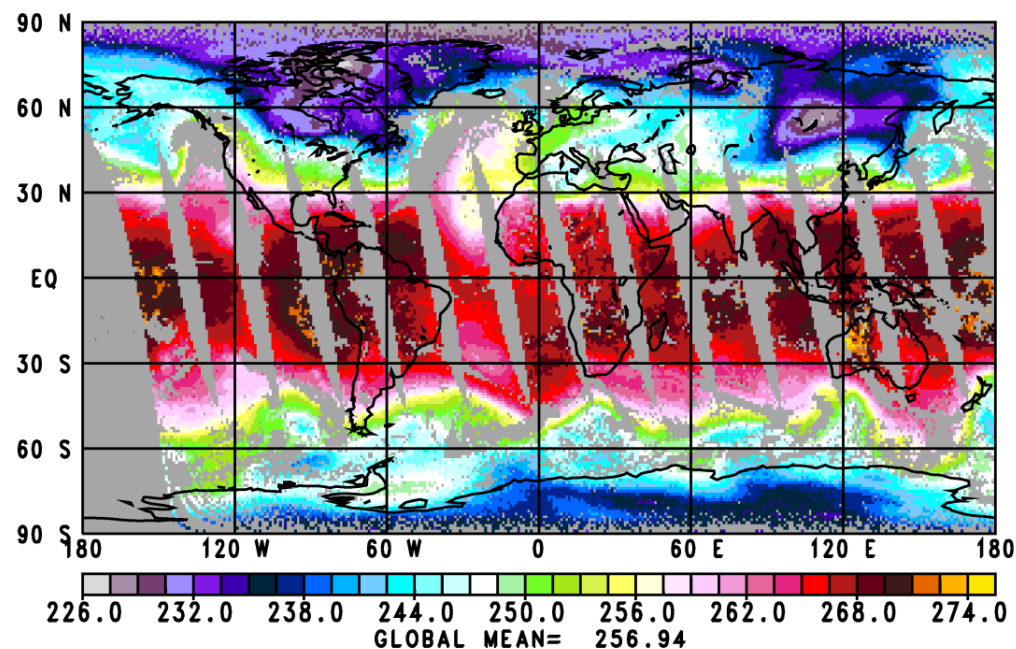
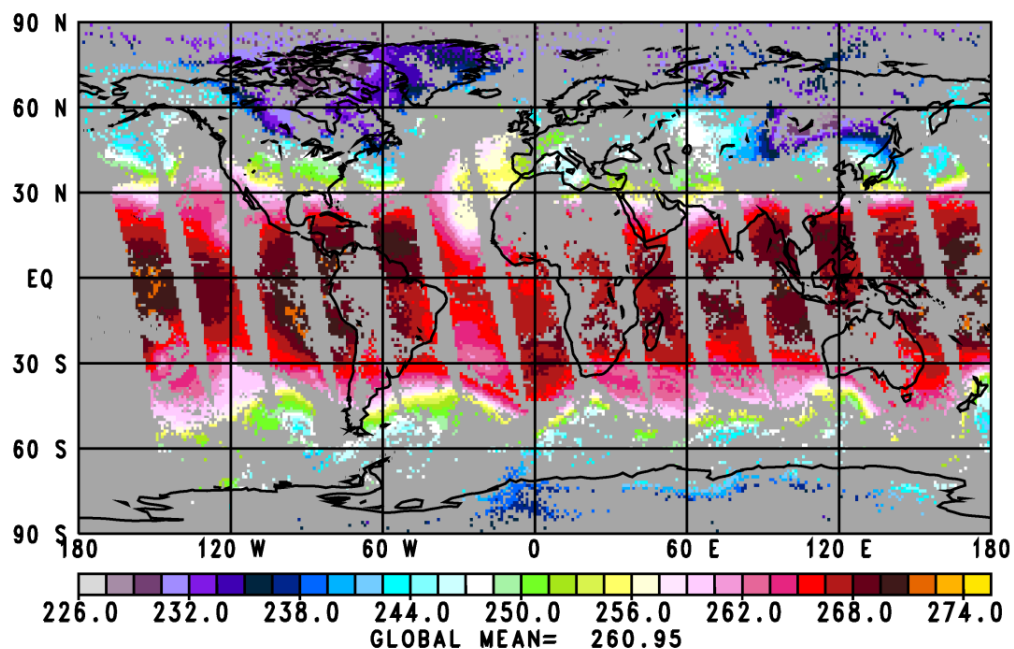


# 500 mb Temperature

January 25, 2003

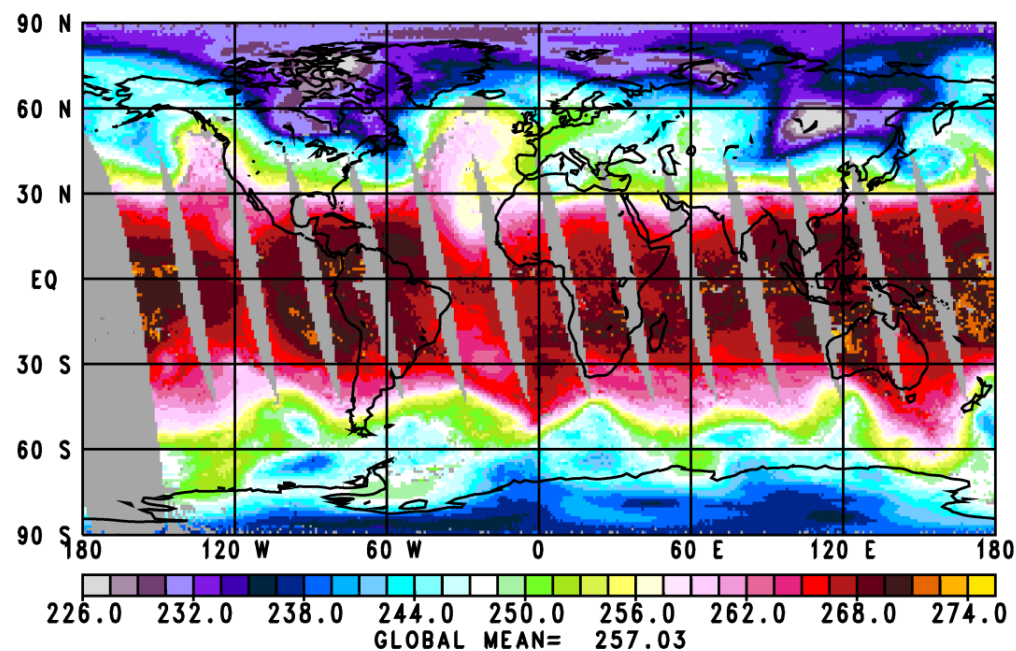
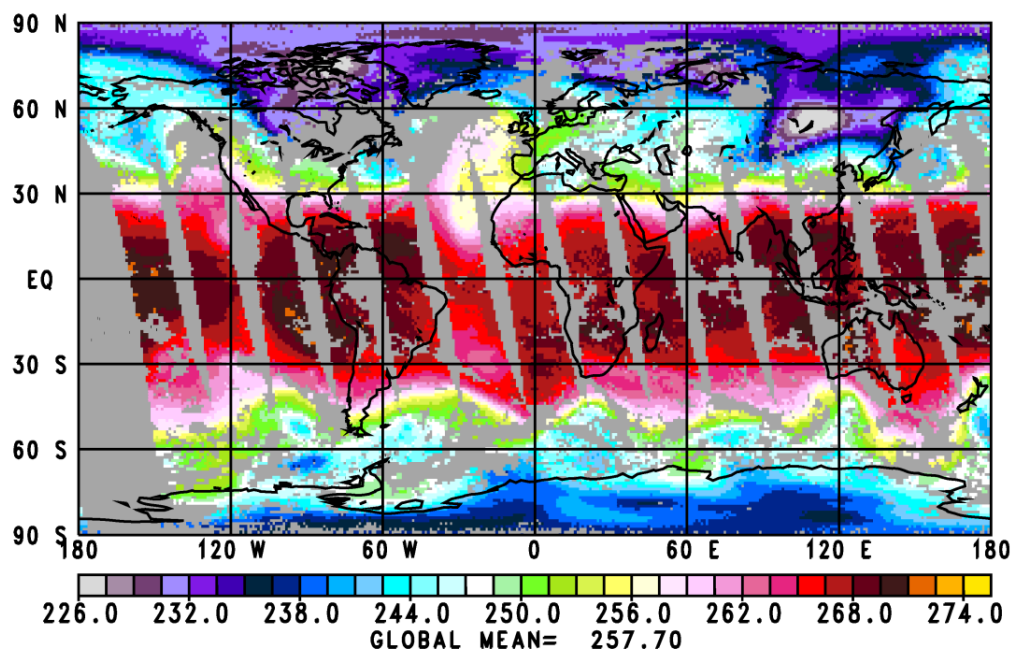
Version-5 Tight QC

Version-5 Standard QC



Version-6 Data Assimilation QC

Version-6 Climate QC



# Forecast Impact Tests using Version-5 T(p)

Forecast impact tests were done at GSFC using GOES-5

Ran four sets of experiments, covering different seasons and years.

January 1 – January 31, 2003

October 15 – November 19, 2005

August 10 – September 16, 2006

April 15 – May 18, 2008

Four sets of assimilations were performed for each time period

Control – uses no AIRS data but all other observations assimilated operationally

Radiance – assimilates AIRS radiances as done operationally

AIRS Standard assimilates AIRS T(p) down to  $p_{\text{best}}$  defined by standard thresholds

AIRS Tight assimilates AIRS T(p) down to  $p_{\text{best}}$  defined by tight thresholds

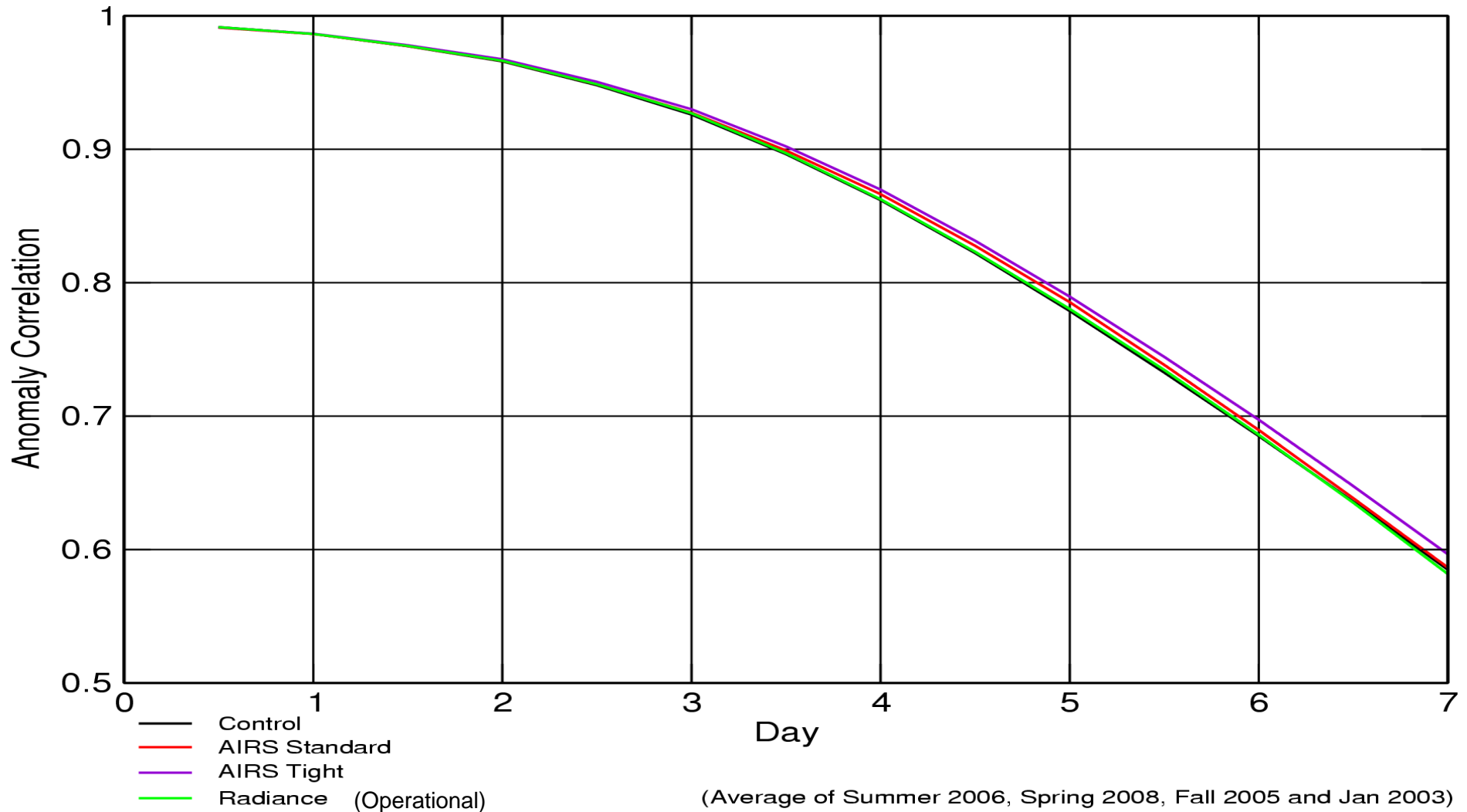
7-day forecasts run from each 0 Z Analysis for each experiment

The accuracy is judged against anomaly correlation of 7-day forecasts vs.

ECMWF Analysis for that time

# 500 mb Geopotential Heights

Global



An anomaly correlation of 1.0 represents a perfect forecast

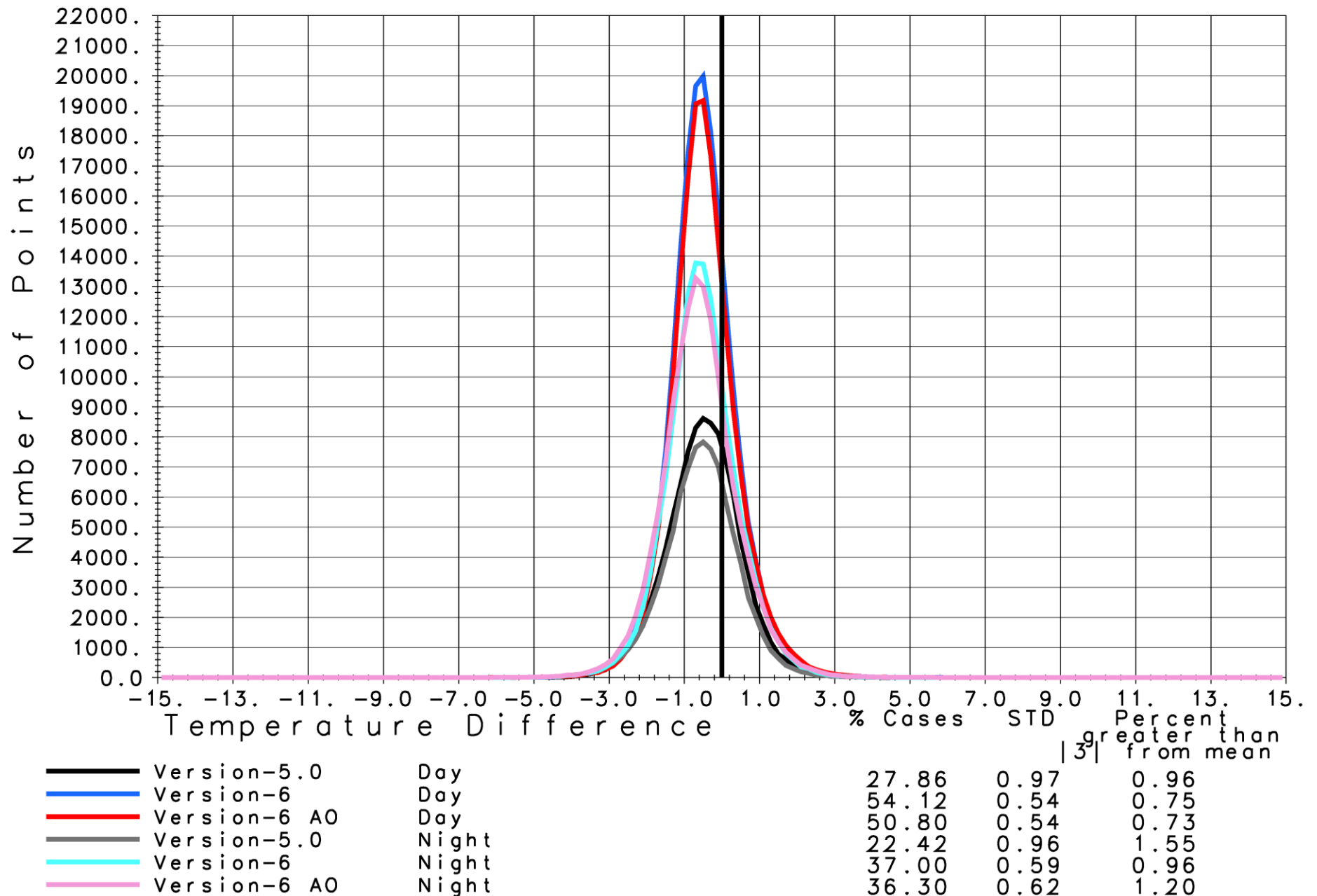
An anomaly correlation of 0.6 is the lower bound of a useful forecast

AIRS Tight improves 7-day forecast skill by about 4 hours.

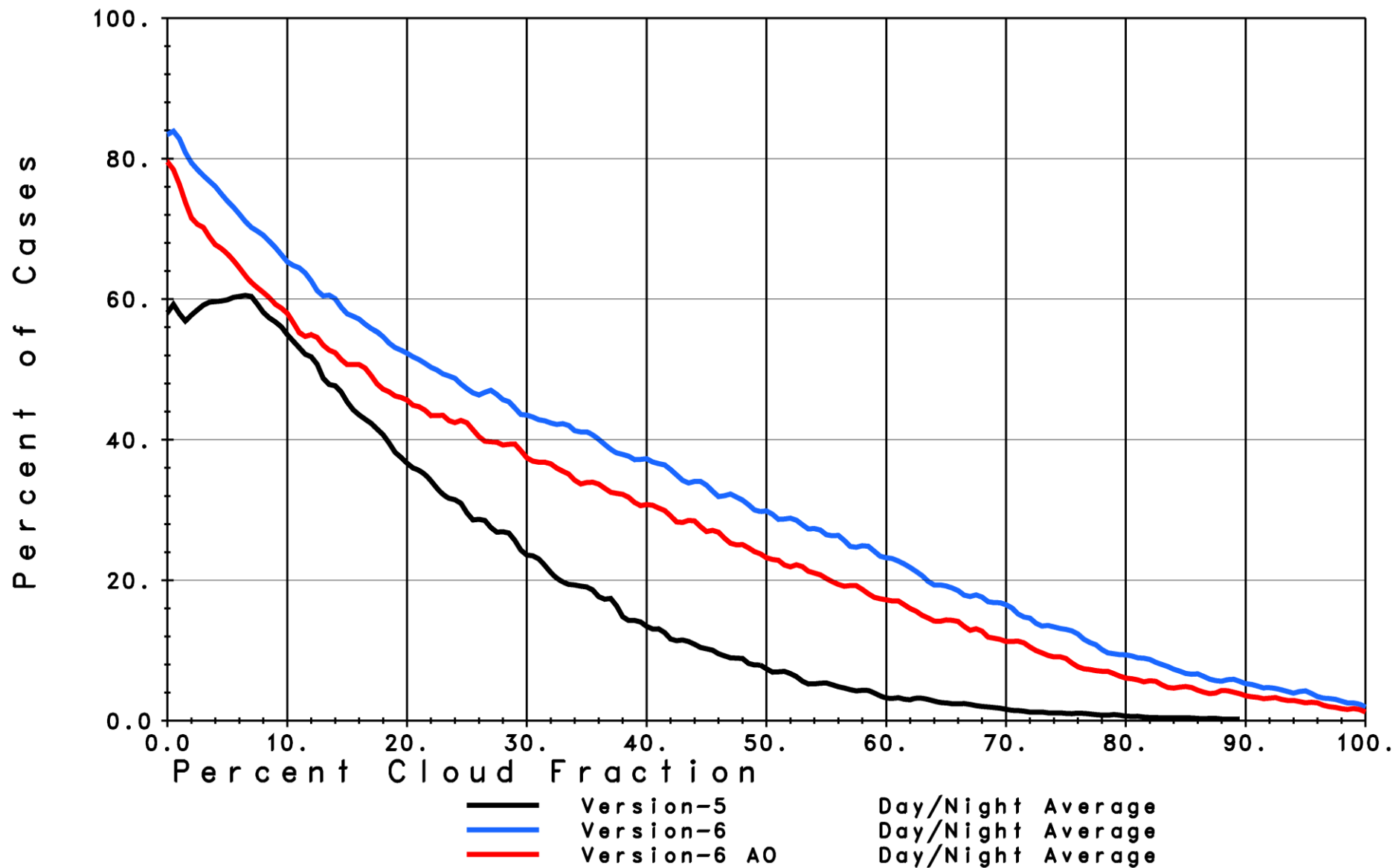
# Sea Surface Temperature Difference from ECMWF

## 6-Day

### 50 N to 50 S Non-Frozen Ocean



Percent Accepted at SST QC vs. Effective Cloud Fraction  
 50N to 50S  
 6-Day



# Summary

AIRS Science Team Version-6 algorithm determines tropospheric  $T(p)$  and  $T_{\text{skin}}$  using only shortwave channels  $2197\text{ cm}^{-1} - 2664\text{ cm}^{-1}$ . The  $15\text{ }\mu\text{m}$  tropospheric sounding  $\text{CO}_2$  channels are used only for cloud clearing (as in Version-5)

## Use of only shortwave channels to determine $T_s$ and tropospheric $T(p)$ results in:

- “AIRS Only” retrievals that are comparable to AIRS/AMSU  
Slightly lower yield with comparable accuracy
- Improved soundings of  $T(p)$  and SST, day and night  
Improvements are larger with increasing cloud cover
- Performance during day is actually superior to performance at night  
- Higher yields and lower errors, especially at larger cloud fraction

This new approach is practical with AIRS because

- Solar radiation reflected by the surface is solved for in the surface retrieval step
- Solar radiation reflected by clouds is accounted for in the cloud clearing step
- **AIRS channels have very low noise at short wavelengths**

This approach is not practical with IASI because shortwave NEDT is too large

It is optimal for future (GEO) high-spectral resolution IR sounders to have low NEDT out to  $2500\text{ cm}^{-1}$ . There is no need for a GEO MW sounder.

